(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) EP 1 244 212 A2

(12) EUROPEAN PATENT APPLICATION

(43) Date of publication:
25.09.2002 Bulletin 2002/39

(51) Int Cl.7: H03H 9/64

(21) Application number: 02290628.3

(22) Date of filing: 12.03.2002

(84) Designated Contracting States:
AT BE CH CY DE DK ES FI FR GB GR IE IT LI LU MC NL PT SE TR
Designated Extension States:
AL LT LV MK RO SI

(30) Priority: 23.03.2001 JP 2001086170

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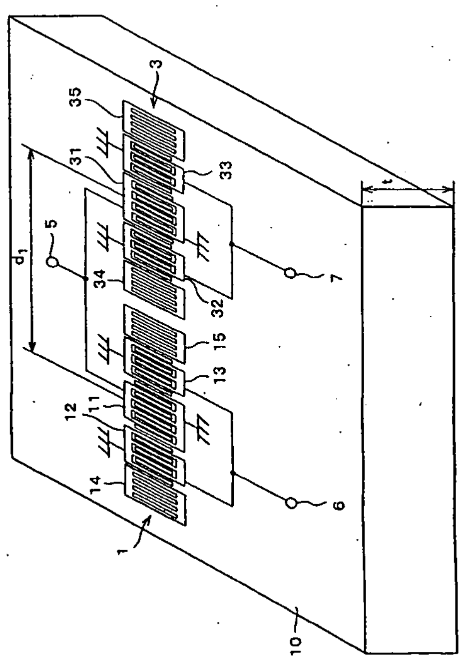
(54) Surface acoustic wave apparatus and communications unit

(57) In a surface acoustic wave (SAW) apparatus, a first SAW filter device (1) and a second SAW filter device (3) are disposed on a piezoelectric substrate (10) so that the propagation paths are overlapped. When the center-to-center distance between the first and second SAW filter devices (1, 3) are indicated by d_1, and when the thickness of the piezoelectric substrate (10) is indicated by t, the first and second SAW filter devices (1, 3) and the piezoelectric substrate (10) are disposed so as to satisfy the condition $d_1 \leq 2.3 \times t$ or $d_1 \geq 2.8 \times t$.

FIG. 1



Printed by Jouve, 75001 PARIS (FR)

Description

[0001] The present invention relates to a surface acoustic wave (SAW) apparatus, such as a SAW filter, and more particularly, to a SAW apparatus having a balanced-to-unbalanced conversion function and having different impedance characteristics at an input side and an output side of the SAW apparatus. The invention also relates to a communications unit using the above-described SAW apparatus.

[0002] There has been significant technological progress in decreasing the size and the weight of portable communications units, such as cellular telephones. One means to achieve such progress is to reduce the number and the size of the individual components of communications units. Additionally, components having composite functions are being developed.

[0003] In view of this background, as a SAW filter used in an RF stage, a balanced filter provided with a balanced-to-unbalanced conversion function (so-called "balun function") or a multi-band filter provided with a plurality of pass bands is employed.

[0004] For example, Japanese Unexamined Patent Application Publication No. 10-117123 discloses a balanced SAW filter unit which implements an unbalanced input and a balanced output by combining SAW filters whose transmission phase characteristics are 180° out of phase with each other. The configuration of the SAW filter unit disclosed in the above publication is shown in Fig. 9.

[0005] The SAW filter unit shown in Fig. 9 has longitudinally-coupled SAW filters 511 and 512. The longitudinally-coupled SAW filter 511 is formed by cascade-connecting SAW filter devices 501a and 501b in two stages by using connecting patterns 520 and 521. The longitudinally-coupled SAW filter 512 is formed by cascade-connecting a SAW filter device 501c and a SAW filter device 502, whose transmission phase characteristics are substantially 180° out of phase with each other, in two stages by using the connecting pattern 521 and a connecting pattern 522.

[0006] In the above-described SAW filter unit, the input terminals of the SAW filter devices 501a and 501c are respectively connected to an unbalanced terminal 503 by wires 530 and 531. The SAW filter devices 501b and 502 are connected in series with each other by a wire 505, and are also respectively connected to output balanced terminals 504 by wires 532 and 533. Terminals 506 are ground terminals, which are respectively connected to the SAW filters devices 501a and 501c by wires 534 and 535.

[0007] An example of the multi-band filter is disclosed in Japanese Unexamined Patent Application Publication No. 10-341135 in which a plurality of SAW filter devices (SAW filters) are provided on a piezoelectric substrate to obtain a plurality of pass bands.

[0008] In the above-described SAW filters having composite SAW filter devices, the plurality of SAW filter devices are formed on the same piezoelectric substrate. In order to reduce the size of such SAW filters, two or more SAW filter devices can be disposed side by side in a SAW propagating direction.

[0009] However, such an arrangement of SAW filter devices may cause ripples in the pass band of a transmission signal due to an influence of bulk waves.

[0010] In RF filters for use in cellular telephones, it is desirable that the transmission characteristics in the pass band be flat. The generation of ripples should be prevented in order to make the transmission characteristics flat.

[0011] One measure to prevent the generation of ripples is to scatter bulk waves by roughening the reverse surface of a piezoelectric substrate (forming undulations by sandblasting). According to this method, however, the piezoelectric substrate may easily break or warp due to heat or stress applied to a wafer during processing.

[0012] In the above-described known SAW filters, the generation of ripples in the pass band is prevented by displacing a plurality of SAW filter devices so that they are not disposed in the corresponding SAW propagating directions. Such an arrangement of the SAW filter devices, however, increases the area of the substrate. Accordingly, there is a demand for a more compact SAW filter (SAW apparatus) in which ripples caused by bulk waves can be reduced without the need to perform sandblasting.

[0013] In order to solve the above-described problems, according to one aspect of the present invention, there is provided a SAW apparatus including: a first SAW filter device having a plurality of interdigital electrodes (interdigital transducers, which are hereinafter referred to as "IDTs") formed on a piezoelectric substrate along a direction in which a SAW propagates; and a second SAW filter device including a plurality of IDTs formed on the piezoelectric substrate along a direction in which a surface acoustic wave propagates. The propagation path of the first SAW filter device is partially overlapped with the propagation path of the second SAW filter device. When the center-to-center distance between the first SAW filter device and the second SAW filter device is indicated by d_1, and when the thickness of the piezoelectric substrate is indicated by t, the first SAW filter device, the second SAW filter device, and the piezoelectric substrate are set so as to satisfy the condition $d_1 \leq 2.3 \times t$ or $d_1 \geq 2.8 \times t$.

[0014] With this arrangement, the above-described SAW apparatus is provided with, not only a filtering function having a specific pass band, but also composite multiple functions by providing a plurality of SAW filter devices.

[0015] In the above-described configuration, since the first SAW filter device, the second SAW filter device, and the piezoelectric substrate are set so as to satisfy the condition $d_1 \leq 2.3 \times t$ or $d_1 \geq 2.8 \times t$, an influence of bulk waves caused by the excited SAW can be inhibited between the first and second SAW filter devices.

[0016] Accordingly, ripples caused by bulk waves occurring in the transmission signal in the pass band can be reduced while achieving a reduced size and multiple functions of the SAW apparatus. Thus, flatter filtering characteristics are obtained so that the transmission characteristics in the pass band can be improved.

[0017] Additionally, according to the above-described configuration, an influence of bulk waves can be inhibited without the need to perform sandblasting (to roughen the reverse surface of the piezoelectric substrate). Thus, a break or a warp of the piezoelectric substrate, which may be caused by roughening the piezoelectric substrate, can be prevented, thereby decreasing the defective fraction of the manufacturing process.

[0018] In the aforementioned SAW apparatus, the transmission amplitude characteristics of the first SAW filter device in the pass band may preferably be substantially the same as those of the second SAW filter device in the pass band. The transmission phase characteristics of the first SAW filter device may preferably be substantially 180° out of phase with those of the second SAW filter device. An input terminal or output terminals may be an unbalanced terminal, and the other terminals may be balanced terminals.

[0019] With the above arrangement, since the transmission phase characteristic of the first SAW filter device is about 180° out of phase with that of the second SAW filter device, a balun function can be provided, thereby making it possible to provide multiple functions for the SAW apparatus.

[0020] In the aforementioned SAW apparatus, the center frequency of the first SAW filter device may be different from that of the second SAW filter device so that the SAW apparatus is operable as a multi-band filter. With this arrangement, the SAW apparatus can be provided with composite multiple functions.

[0021] According to another aspect of the present invention, there is provided a SAW apparatus including first through fourth SAW filter devices, each having a plurality of IDTs formed on a piezoelectric substrate along a direction in which a SAW propagates. The first SAW filter device and the third SAW filter device are cascade-connected, and the second SAW filter device and the fourth SAW filter device are cascade-connected. The propagation path of the first SAW filter device is partially overlapped with that of the second SAW filter device, and the propagation path of the third SAW filter device is partially overlapped with that of the fourth SAW filter device. When the center-to-center distance between the first SAW filter device and the second SAW filter device is indicated by d_1, when the center-to-center distance between the third SAW filter device and the fourth SAW filter device is indicated by d_2, and when a wavelength of a SAW to be excited is indicated by λ, the first through fourth SAW filter devices are disposed so that the center-to-center distance d_1 is differentiated from the center-to-center distance d_2 by an amount equal to approximately $(2n+1) \times 0.5\lambda$ ($n = 0, 1, 2, 3$, and so on).

[0022] With the above configuration, by providing the first through fourth SAW filter devices, a filtering function provided with a specific pass band can be implemented, and composite multiple functions can be obtained.

[0023] In the above-described configuration, the center-to-center distance d_1 is differentiated from the center-to-center distance d_2 by an amount equal to about $(2n+1) \times 0.5\lambda$ ($n = 0, 1, 2, 3$, and so on), i.e., substantially a multiple of an odd number, of the SAW half-wavelength. Accordingly, even if the first and second SAW filter devices are located in close proximity with the third and fourth SAW filter devices for the miniaturization of the SAW apparatus, ripples occurring between the first and second SAW filter devices and the third and fourth SAW filter devices caused by bulk waves can be reduced.

[0024] Thus, a filtering function can be provided, and also, generation of ripples can be reduced while achieving a smaller SAW apparatus provided with multiple functions. Accordingly, flatter filtering characteristics can be obtained, thereby improving the transmission characteristics in the pass band.

[0025] In the aforementioned SAW apparatus, the transmission amplitude characteristics of the first through fourth SAW filter devices in the pass band may be substantially the same. Three of the first through fourth SAW filter devices may have substantially the same transmission phase characteristics, and the transmission phase characteristic of the remaining SAW filter device may be 180° out of phase with that of the other SAW filter devices. One of an input terminal and output terminals may be an unbalanced terminal, and the other terminals may be balanced terminals.

[0026] With this arrangement, by setting one of the SAW filter devices out of phase with the other three SAW filter devices, a balun function can be provided, thereby achieving multiple functions.

[0027] In the aforementioned SAW apparatus, when the thickness of the piezoelectric substrate is indicated by t, the first through fourth SAW filter devices and the piezoelectric substrate may be set so as to satisfy conditions $d_1 \leq 2.3 \times t$ or $d_1 \geq 2.8 \times t$ and $d_2 \leq 2.3 \times t$ or $d_2 \geq 2.8 \times t$.

[0028] With this arrangement, by setting the center-to-center distances d_1 and d_2 as described above, the generation of ripples can be inhibited, thereby improving the transmission characteristics.

[0029] In the aforementioned SAW apparatus, the piezoelectric substrate may be a 36° to 44° Y-cut X-propagating $LiTaO_3$ substrate. Then, the insertion loss can be reduced by high piezoelectric characteristics, and an influence of the environmental temperature can be inhibited by excellent temperature characteristics.

[0030] A communications unit of the present invention uses one of the aforementioned SAW apparatuses.

[0031] With this configuration, since a compact and multi-function SAW apparatus exhibiting excellent

transmission characteristics is used, the communications unit can be miniaturized while exhibiting a good transmission/reception function.

[0032] The above and other aspects, features and advantages of the present invention will become clear from the following detailed description of preferred embodiments thereof, given by way of example, with reference to the accompanying drawings, in which:

Fig. 1 is a perspective view schematically illustrating a SAW filter according to a first embodiment of the present invention;
Fig. 2 illustrates the concept of the radiation of a bulk wave occurring in the SAW filter shown in Fig. 1;
Fig. 3 illustrates the amount of rippling with respect to a change in the center-to-center distance d_1 in the SAW filter shown in Fig. 1;
Fig. 4 is a perspective view schematically illustrating a SAW filter according to a second embodiment of the present invention;
Fig. 5 illustrates the cancellation of ripples occurring in the SAW filter shown in Fig. 4;
Fig. 6 illustrates improved filtering characteristics obtained in the SAW filter shown in Fig. 4 in comparison with filtering characteristics of a known SAW filter;
Fig. 7 is a perspective view schematically illustrating a SAW filter according to a third embodiment of the present invention;
Fig. 8 is a block diagram illustrating the basic portions of a communications unit according to a fourth embodiment of the present invention; and
Fig. 9 is a plan view schematically illustrating a known SAW apparatus.

[0033] The present invention is described in detail below with reference to Figs. 1 through 8 through illustration of preferred embodiments.

First Embodiment

[0034] Fig. 1 is a perspective view schematically illustrating the structure of a SAW filter which serves as a SAW apparatus according to a first embodiment of the present invention. In the SAW filter shown in Fig. 1, a first SAW filter device 1 and a second SAW filter device 3, whose transmission phase characteristics are about 180° out of phase with each other, are formed on a piezoelectric substrate 10.

[0035] The piezoelectric substrate 10 is formed of, for example, 39° Y-cut X-propagating $LiTaO_3$, and the thickness t thereof is, for example, 285 μm. The piezoelectric substrate 10 is not restricted to the above-described material, but may be formed of another material which exhibits a different type of piezoelectric characteristic, for example, quartz or $LiNbO_3$.

[0036] The basic structures of the first and second SAW filter devices 1 and 3 are the same, e.g., their center frequencies are 842.5 MHz. However, the transmission phase characteristic of the second SAW filter device 3 is 180° out of phase with that of the first SAW filter device 1. With this arrangement, the SAW filter is provided with, not only a filtering function, but also a balun function.

[0037] In the first SAW filter device 1, IDTs 12 and 13 are respectively disposed at the left and right sides of a central IDT 11 in a SAW propagating direction. Reflectors 14 and 15 are disposed such that they flank the IDT 12, the central IDT 11, and the IDT 13 from the left and right sides. Also in the second SAW filter device 3, an IDT 32, a central IDT 31, an IDT 33, and reflectors 34 and 35 are disposed in a manner similar to the first SAW filter device 1. Accordingly, the first and second SAW filter devices 1 and 3 are longitudinally-coupled devices.

[0038] The IDTs each have a strip-like base portion (bus bar) and two electrode portions provided with a plurality of strip-like electrode fingers. The electrode fingers extend orthogonally from one side of the base portion such that they are parallel to each other. The electrode fingers also interdigitate with each other with equal gaps such that the sides thereof face each other.

[0039] In the above-configured IDTs, the signal conversion characteristics and the pass band can be determined by setting the length and the width of each electrode finger, the gap between adjacent electrode fingers, and the length by which interdigitated electrode fingers face each other (hereinafter referred to as the "interdigital length").

[0040] The individual electrode fingers and the bus bars of the IDTs and the reflectors are formed of, for example, aluminum (Al) electrodes (foil) on the piezoelectric substrate 10 according to, for example, a photolithographic technique.

[0041] An unbalanced terminal 5 is connected to the central IDT 11 of the first SAW filter device 1 and the central IDT 31 of the second SAW filter device 3. One balanced terminal 6 is connected to the IDTs 12 and 13 of the first SAW filter device 1, while the other balanced terminal 7 is connected to the IDTs 32 and 33 of the second SAW filter device 3.

[0042] The first and second SAW filter devices 1 and 3 are disposed adjacent to each other in the SAW propagating direction, and the center-to-center distance d_1 is set to, for example, 620.0 μm. The center of the first SAW filter device 1 means the center of the distance between the two ends of the IDTs 12, 11, and 13, excluding the reflectors 14 and 15, and more specifically, the center of the distance from the end of the electrode finger of the IDT 12 adjacent to the reflector 14 to the end of the electrode finger of the IDT 13 adjacent to the reflector 15. Similarly, the center of the second SAW filter device 3 means the center of the distance between the two ends of the IDTs 32, 31, and 33, excluding the reflectors 34 and 35, and more specifically, the center of the distance from the end of the electrode finger of

the IDT 32 adjacent to the reflector 34 to the end of the electrode finger of the IDT 33 adjacent to the reflector 35.

[0043] As described above, the first SAW filter device 1 and the second SAW filter device 3 are disposed adjacent to each other in the SAW propagating direction, and more preferably, the center line of the propagating direction of the first SAW filter device 1 is substantially aligned with that of the second SAW filter device 3. With this arrangement, the size of the piezoelectric substrate 10 can be reduced, and the resulting SAW filter can also be miniaturized while achieving a SAW filter with multiple functions.

[0044] Only a few pairs of electrode fingers of each SAW filter device and a few electrode fingers of each reflector are shown in Fig. 1 since all of them cannot be shown.

[0045] In the above-described SAW filter, an electrical signal is converted into a SAW by the IDTs 11 and 31 at the input side, and the SAW is re-converted into an electrical signal by the IDTs 12, 13, 32, and 33 at the output side, so that the frequency can be selected. Thus, the SAW filter serves as a filter.

[0046] In the above-described SAW filter, a SAW excited by the IDTs propagates on the surface of the piezoelectric substrate 10, and bulk waves, which cause ripples, also propagate within the piezoelectric substrate 10.

[0047] The bulk waves are strongly dependent on direction, and the radiation angle is restricted to a certain range. As shown in Fig. 2, a bulk wave 8 radiated from the first SAW filter device 1 is reflected at a bottom surface 10a of the piezoelectric substrate 10 and returns to an obverse surface 10b at a certain angle. In this case, if the bulk wave 8 returns to a portion close to the second SAW filter device 3, it is strongly influenced by the second SAW filter device 3, thereby causing undesirable ripples in the transmission characteristics in the pass band.

[0048] By performing various studies to achieve filtering characteristics whose transmission characteristics in the pass band become flatter by avoiding an adverse influence of the bulk wave 8, we have discovered the following feature. The central IDT 31 of the second SAW filter device 3 adjacent to the first SAW filter device 1 should be disposed on a portion of the obverse surface 10b where it does not interfere with the bulk wave 8 radiated from the first SAW filter device 1 and returned from the bottom surface 10a.

[0049] Then, we examined the relationship between the center-to-center distance d_1 between the first and second SAW filter devices 1 and 3 and the amount of rippling occurring in the pass band by varying the center-to-center distance d_1. The thickness t of the piezoelectric substrate 10 was also changed to examine the relationship between the center-to-center distance d_1 and the amount of rippling. The results are shown in Fig. 3.

[0050] Fig. 3 reveals that the amount of rippling in the pass band is increased, i.e., 0.15 dB or greater, when the center-to-center distance d_1 is in a range of $2.3t < d_1 < 2.8t$.

[0051] Accordingly, the first and second SAW filter devices 1 and 3 should be disposed so that the center-to-center distance d_1 is outside the above-described range, thereby making it possible to reduce the amount of rippling.

[0052] When the center-to-center distance d_1 is 2.3t or smaller ($d_1 \leq 2.3 \times t$), or 2.8t or greater ($d_1 \geq 2.8 \times t$), the advantages of the present invention can be achieved. More preferably, however, the center-to-center distance d_1 is in a range of $1.6t \leq d_1 \leq 2.3t$ or $2.8t \leq d_1 \leq 3.5t$, and even more preferably, in a range of $1.7t \leq d_1 \leq 2.1t$ or $2.9t \leq d_1 \leq 3.3t$. If d_1 exceeds 3.5t, miniaturization of the SAW filter becomes difficult. If d_1 is less than 1.6t, the number of electrode fingers of the reflectors is reduced, thus increasing spurious responses outside the pass band.

Second Embodiment

[0053] Fig. 4 is a perspective view schematically illustrating the structure of a SAW filter which serves as a SAW apparatus according to a second embodiment of the present invention. In the second embodiment, the components having functions similar to those of the SAW filter of the first embodiment are indicated by like reference numerals, and an explanation thereof is thus omitted.

[0054] The SAW filter shown in Fig. 4 is a two-stage longitudinally-coupled SAW filter provided with, not only the first and second SAW filter devices 1 and 3, but also third and fourth SAW filter devices 2 and 4 (having a center frequency of 942.5 MHz) on the piezoelectric substrate 10.

[0055] The transmission phase characteristics of the second SAW filter 3 are about 180° out of phase with those of the first, third, and fourth SAW filter devices 1, 2, and 4. With this arrangement, the above-described SAW filter is provided with, not only a filtering function, but also a balun function.

[0056] In the second embodiment, the transmission phase characteristics of the second SAW filter device 3 are 180° out of phase with the other SAW filter devices. However, it does not have to be the second SAW filter device 3; any one of the SAW filter devices 1, 2, 4 can be set to 180° out of phase with the other SAW devices, in which case, advantages similar to those offered by the second embodiment can be exhibited.

[0057] The first and third SAW filter devices 1 and 2 are cascade-connected with each other, and the second and fourth SAW filter devices 3 and 4 are cascade-connected with each other. The SAW filter devices 1 through 4 are disposed so that the propagating direction of the SAW filter devices 1 and 3 is substantially parallel to that of the SAW filter devices 2 and 4. With this arrangement, the size of the resulting SAW filter can be reduced while

achieving multiple functions.

[0058] The unbalanced terminal 5 of the SAW filter is connected to the central IDT 11 of the first SAW filter device 1 and the central IDT 31 of the second SAW filter device 3. One balanced terminal 6 is connected to a central IDT 21 of the third SAW filter device 2, while the other balanced terminal 7 is connected to a central IDT 41 of the fourth SAW filter device 4.

[0059] The first and second SAW filter devices 1 and 3 are disposed adjacent to each other in the SAW propagating direction, and the center-to-center distance d_1 between the first and second SAW filter devices 1 and 3 is, for example, 620.0 μm. The center of the first SAW filter device 1 means the center of the distance between two ends of the IDTs 12, 11, and 13, excluding the reflectors 14 and 15, and more specifically, the center of the distance from the end of the electrode finger of the IDT 12 adjacent to the reflector 14 to the end of the electrode finger of the IDT 13 adjacent to the reflector 15. The center of the second SAW filter device 3 can be calculated in a manner similar to the first SAW filter device 1.

[0060] The third and fourth SAW filter devices 2 and 4 are disposed adjacent to each other in the SAW propagating direction, and the center-to-center distance d_2 between the third and fourth SAW filter devices 2 and 4 corresponding to the center-to-center distance d_1 is, for example, 522.1 μm. Only a few pairs of SAW filter devices and a few reflectors are shown in Fig. 4 since all of them cannot be shown.

[0061] In the second embodiment, a SAW filter provided with a balun function is configured by using the two-stage cascade-connected SAW filter devices 1 through 4.

[0062] In this SAW filter, an electrical signal is converted into a SAW by the IDTs 11 and 31 at the input side, and the SAW is re-converted into an electrical signal by the IDTs 21 and 41 at the output side so that the frequency can be selected. Thus, the SAW filter serves as a filter.

[0063] As discussed above, in the second embodiment, the center-to-center distance d_1 between the first-stage SAW filter devices 1 and 3 is differentiated from the center-to-center distance d_2 of the second-stage SAW filter devices 2 and 4. This is discussed in detail below.

[0064] The center-to-center distance d_1 of the first-stage SAW filter devices 1 and 3 is differentiated from the center-to-center distance d_2 of the second-stage SAW filter devices 2 and 4 by an amount equal to $(2n+1)/2$ times ($n = 0, 1, 2, 3$, and so on) the SAW wavelength, thereby further reducing the amount of rippling in the pass band caused by bulk waves.

[0065] Ripples caused by bulk waves discussed in the first embodiment occur depending on the phase relationship between the SAW excited by the SAW filter devices and the bulk wave.

[0066] More specifically, when the SAW and the bulk wave are in phase, the two waves strengthen each other. Conversely, when the SAW is 180° out of phase with the bulk wave, the two waves weaken each other. As shown in (a) of Fig. 5, undulations (ripples) occur, as indicated by the solid line, in the filtering characteristics (transmission characteristics) of the first-stage SAW filter devices 1 and 3. As shown in (b) of Fig. 5, undulations (ripples) occur, as indicated by the solid line, in the filtering characteristics of the second-stage SAW filter devices 2 and 4. The broken lines in (a) and (b) of Fig. 5 indicate the filtering characteristics unaffected by bulk waves.

[0067] If the undulations of the transmission characteristics shown in (a) of Fig. 5 are inverted with those shown in (b) of Fig. 5, they cancel each other in the entire two-stage cascade-connected filter, resulting in filtering characteristics without ripples. The undulations can be canceled by implementing an inverted phase relationship between the SAW and the bulk wave. This can be achieved by displacing the center-to-center distance of the first-stage SAW filter devices from that of the second-stage SAW filter devices by $(2n+1)/2$ times ($n = 0, 1, 2, 3$, and so on) the wavelength of a SAW to be excited.

[0068] The phase characteristics of the SAW are determined by the structure of the electrode fingers of each SAW filter device 1, 2, 3 or 4 rather than the arrangement of the SAW filter devices 1 through 4. In contrast, concerning the bulk wave, the propagation path length is changed according to the arrangement of the SAW filter devices 1 through 4, and the phase characteristics of the bulk wave are changed accordingly.

[0069] There is a certain relationship between a SAW excited within a SAW filter device and a bulk wave to be radiated. Thus, if the center-to-center distance of the SAW filter devices is changed by an amount equal to one wavelength, the propagation path length of the bulk wave can also be changed by an amount equal to one wavelength.

[0070] Accordingly, the center-to-center distance d_1 of the first-stage SAW filter devices 1 and 3 is differentiated from the center-to-center distance d_2 of the second-stage SAW filter devices 2 and 4 by an amount equal to $(2n+1)/2$ times ($n = 0, 1, 2, 3$, and so on) the SAW wavelength. Then, the undulations generated by the bulk wave in the first-stage SAW filter devices 1 and 3 are inverted with respect to those in the second-stage SAW filter devices 2 and 4, and cancel each other in the overall two-stage cascade-connected filter. As a result, filtering characteristics without ripples can be obtained, as shown in (c) of Fig. 5.

[0071] Fig. 6 illustrates the improved filtering characteristics obtained in the second embodiment in comparison with the filtering characteristics of a known SAW filter. In the known SAW filter (comparative example), the center-to-center distances of the SAW filter devices and the thickness of the piezoelectric substrate are determined as follows: $d_1 = d_2 = 620$ μm and $t = 285$ μm.

Fig. 6 reveals that the filtering characteristics obtained in the second embodiment exhibit excellent characteristics without ripples in comparison with the comparative example.

[0072] As in the first embodiment, in the second embodiment, the center-to-center distances d_1 and d_2 can be set relative to the thickness t of the piezoelectric substrate 10, thereby achieving better transmission characteristics.

Third Embodiment

[0073] Fig. 7 is a perspective view schematically illustrating a multi-band SAW filter which serves as a multifunction SAW apparatus according to a third embodiment of the present invention. The components having functions similar to those of the SAW filters of the first and second embodiments are indicated by like reference numerals, and an explanation thereof is thus omitted.

[0074] In the SAW filter shown in Fig. 7, a SAW filter device 301 having a center frequency of 895.5 MHz and a SAW filter device 302 having a center frequency of 942.5 MHz are formed on the piezoelectric substrate 10 so as to provide two pass bands.

[0075] The SAW filter devices 301 and 302 are configured similarly to the SAW filter device 1 of the first or second embodiment, except that the center frequencies of the SAW filter devices 301 and 302 are different from each other.

[0076] Only a few pairs of electrode fingers of each SAW filter device 301 or 302 and a few electrode fingers of the reflectors are shown in Fig. 7 since all of them cannot be shown. The center-to-center distance d_1 between the SAW filter devices 301 and 302 in a SAW propagating direction is set to, for example, 620 μm.

[0077] Unlike the first embodiment, in the third embodiment, the SAW filter devices 301 and 302 have different center frequencies and are disposed adjacent to each other. However, even though the center frequencies are different, the radiation angle of the bulk wave 8 is unchanged.

[0078] Accordingly, if the center-to-center distance d_1 between the SAW filter devices 301 and 302 is set to a range of $2.3t < d_1 < 2.8t$, ripples occur in the transmission signal in the pass band for the same reason as that discussed in the first embodiment.

[0079] Thus, the SAW filter devices 301 and 302 are disposed so that the center-to-center distance d_1 is outside the above-described range. Then, ripples occurring in the transmission signal in the pass band can be reduced. The features of the third embodiment are applicable to the second embodiment, in which case, advantages similar to those exhibited by the third embodiment can be obtained.

Fourth Embodiment

[0080] A description is now given, with reference to Fig. 8, of a communications unit 100 according to a fourth embodiment of the present invention on which one of the SAW filters of the first through third embodiments is mounted. In the communications unit 100, as shown in Fig. 8, a receiver (Rx) includes an antenna 101, an antenna sharing portion/RF top filter 102, an amplifier 103, an Rx section filter 104, a mixer 105, a first IF filter 106, a mixer 107, a second IF filter 108, a first-and-second-signal local synthesizer 111, a temperature-compensated crystal oscillator (TCXO) 112, a divider 113, and a local filter 114.

[0081] As indicated by two lines between the Rx section filter 104 and the mixer 105 shown in Fig. 8, two balanced signals are preferably transmitted from the Rx section filter 104 to the mixer 105 in order to maintain the balanced characteristics.

[0082] In the communications unit 100, a transmitter (Tx) includes the antenna 101, the antenna sharing portion/RF top filter 102, a Tx IF filter 121, a mixer 122, a Tx section filter 123, an amplifier 124, a coupler 125, an isolator 126, and an automatic power control (APC) device 127. The antenna 101 and the antenna sharing portion/RF top filter 102 are shared by the receiver (Rx) and the transmitter (Tx).

[0083] Any one of the SAW filters of the first through third embodiments is suitable for use as any one of the Rx section filter 104, the first IF filter 106, the Tx IF filter 121, and the Tx section filter 123.

[0084] Accordingly, in the above-described communications unit 100, since a compact and multi-functional SAW filter exhibiting excellent transmission characteristics is used, the communications unit 100 is also provided with a good transmission/reception function and can be miniaturized, in particular, in a GHz band or higher.

Claims

1. A surface acoustic wave apparatus comprising:

    a first surface acoustic wave filter device (1) including a plurality of interdigital electrodes (11, 12, 13) formed on a piezoelectric substrate (10) along a direction in which a surface acoustic wave propagates; and

    a second surface acoustic wave filter device (3) including a plurality of interdigital electrodes (31, 32, 33) formed on said piezoelectric substrate (10) along a direction in which a surface acoustic wave propagates, a propagation path of said first surface acoustic wave filter device (1) being partially overlapped with a propagation path of said second surface acoustic wave filter device (3),

wherein, when the center-to-center distance between said first surface acoustic wave filter device (1) and said second surface acoustic wave filter device (3) is indicated by d_1, and when the thickness of said piezoelectric substrate (10) is indicated by t, said first surface acoustic wave filter device (1), said second surface acoustic wave filter device (3), and said piezoelectric substrate (10) are set so as to satisfy a condition $d_1 \leq 2.3 \times t$ or $d_1 \geq 2.8 \times t$.

2. A surface acoustic wave apparatus according to claim 1, wherein:

transmission amplitude characteristics of said first surface acoustic wave filter device (1) in a pass band are substantially the same as transmission amplitude characteristics of said second surface acoustic wave filter device (3) in a pass band, and transmission phase characteristics of said first surface acoustic wave filter device (1) are substantially 180° out of phase with transmission phase characteristics of said second surface acoustic wave filter device (3); and

an input terminal (5) or output terminals (6, 7) is an unbalanced terminal, and the other terminals are balanced terminals.

3. A surface acoustic wave apparatus according to claim 1 or 2, wherein a center frequency of said first surface acoustic wave filter device (1) is different from a center frequency of said second surface acoustic wave filter device (3) so that said surface acoustic wave apparatus is operable as a multiband filter.

4. A surface acoustic wave apparatus comprising:

a first surface acoustic wave filter device (1) including a plurality of interdigital electrodes formed on a piezoelectric substrate (10) along a direction in which a surface acoustic wave propagates;

a second surface acoustic wave filter device (3) including a plurality of interdigital electrodes formed on said piezoelectric substrate (10) along a direction in which a surface acoustic wave propagates;

a third surface acoustic wave filter device (2) including a plurality of interdigital electrodes formed on said piezoelectric substrate (10) along a direction in which a surface acoustic wave propagates; and

a fourth surface acoustic wave filter device (4) including a plurality of interdigital electrodes formed on said piezoelectric substrate (10) along a direction in which a surface acoustic wave propagates, said first surface acoustic wave filter device (1) and said third surface acoustic wave filter device (2) being cascade-connected, said second surface acoustic wave filter device (3) and said fourth surface acoustic wave filter device (4) being cascade-connected, a propagation path of said first surface acoustic wave filter device (1) being partially overlapped with a propagation path of said second surface acoustic wave filter device (3), and a propagation path of said third surface acoustic wave filter device (2) being partially overlapped with a propagation path of said fourth surface acoustic wave filter device (4),

wherein, when the center-to-center distance between said first surface acoustic wave filter device (1) and said second surface acoustic wave filter device (3) is indicated by d_1, when the center-to-center distance between said third surface acoustic wave filter device (2) and said fourth surface acoustic wave filter device (4) is indicated by d_2, and when a wavelength of a surface acoustic wave to be excited is indicated by λ, said first through fourth surface acoustic wave filter devices (1, 3, 2, 4) are disposed so that the center-to-center distance d_1 is differentiated from the center-to-center distance d_2 by an amount equal to approximately $(2n+1) \times 0.5\lambda$ (n = 0, 1, 2, 3, and so on).

5. A surface acoustic wave apparatus according to claim 4, wherein:

transmission amplitude characteristics of said first through fourth surface acoustic wave filter devices (1, 3, 2, and 4) in a pass band are substantially the same, and three of said first through fourth surface acoustic wave filter devices (1, 3, 2, 4) have substantially the same transmission phase characteristics, the transmission phase characteristics of the remaining surface acoustic wave filter device being substantially 180° out of phase with the transmission phase characteristics of the other surface acoustic wave filter devices; and

one of an input terminal (5) and output terminals (6, 7) is an unbalanced terminal, and the other terminals are balanced terminals.

6. A surface acoustic wave apparatus according to one of claims 4 and 5, wherein, when the thickness of said piezoelectric substrate (10) is indicated by t, said first through fourth surface acoustic wave filter devices (1, 3, 2, and 4) and said piezoelectric substrate (10) are set so as to satisfy conditions $d_1 \leq 2.3 \times t$ or $d_1 \geq 2.8 \times t$ and $d_2 \leq 2.3 \times t$ or $d_2 \geq 2.8 \times t$.

7. A surface acoustic wave apparatus according to

any one of claims 1 to 6, wherein said piezoelectric substrate (10) is a 36° to 44° Y-cut X-propagating $LiTaO_3$ substrate.

8. A communication unit using the surface acoustic wave apparatus set forth in any one of claims 1 to 7.

FIG. 1

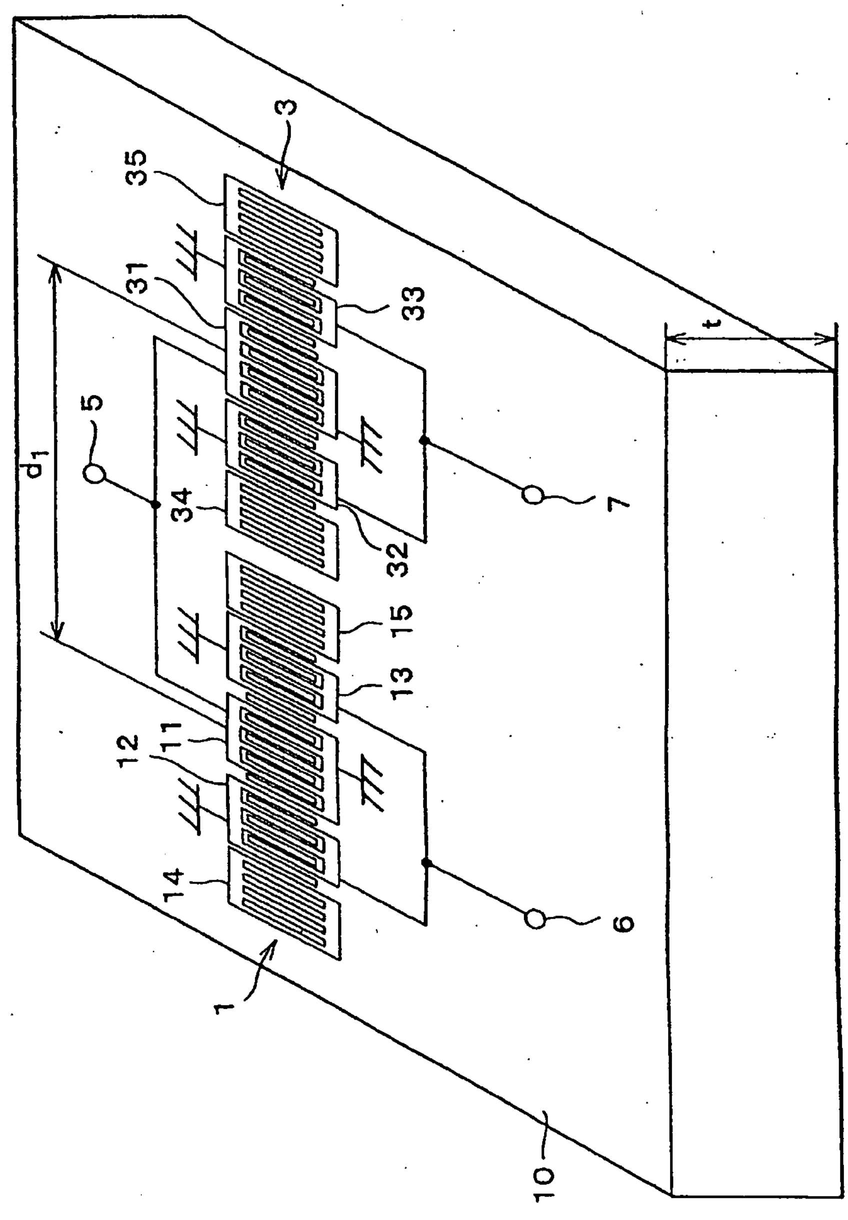


FIG. 2

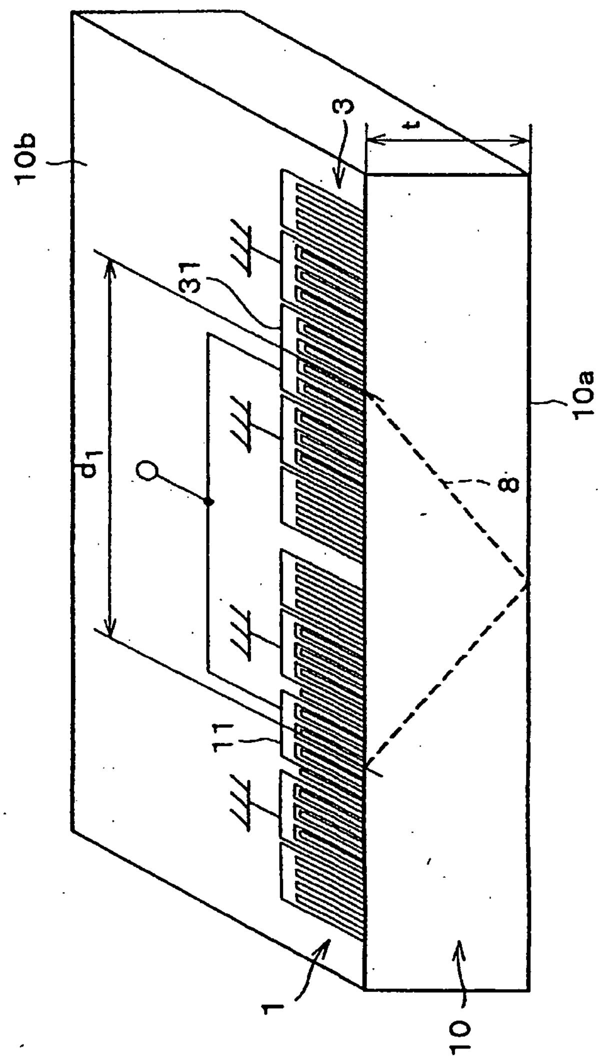


FIG. 3

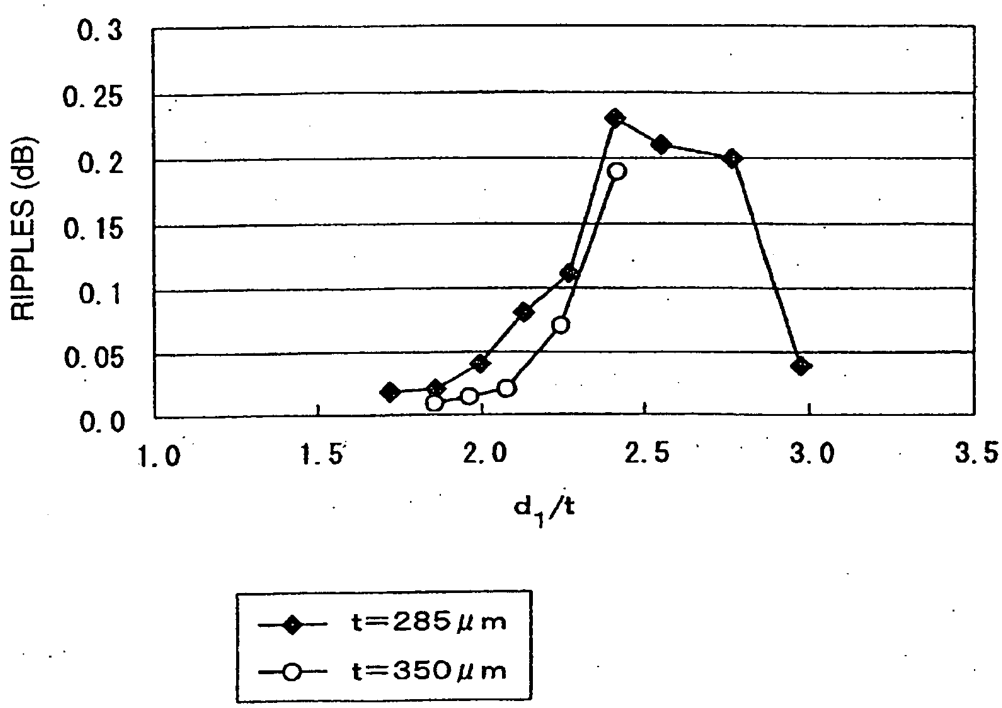

0.3
0.25
0.2
0.15
0.1
0.05
0.0
RIPPLES (dB)
1.0
1.5
2.0
2.5
3.0
3.5
d1/t
t=285μm
t=350μm

FIG. 4

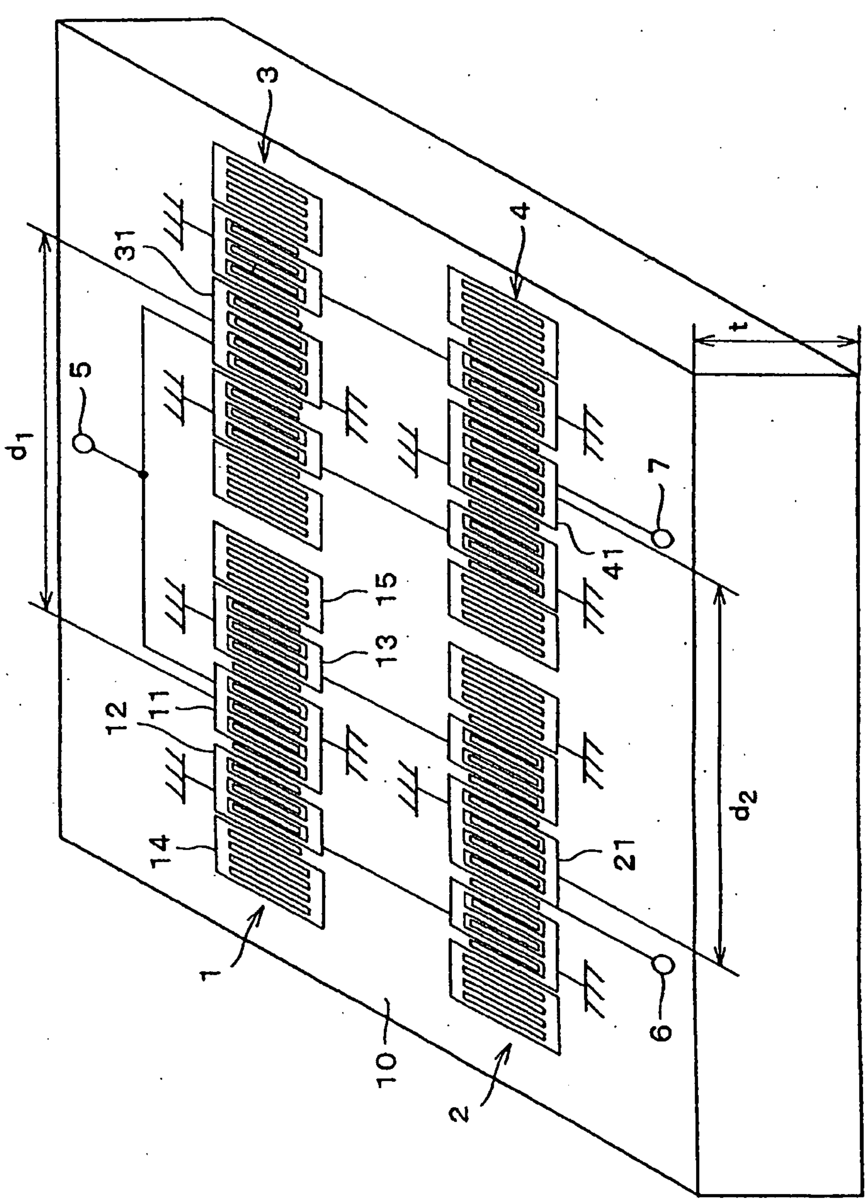
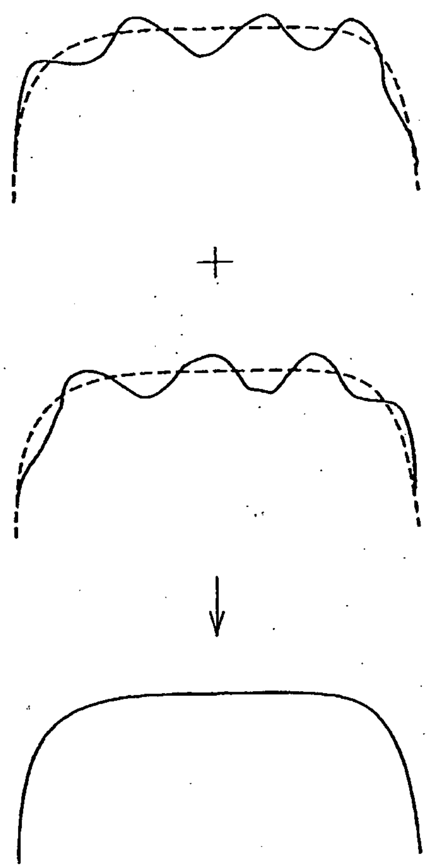


FIG. 5



(a)

First-Stage Filtering Characteristics
(Broken Line Indicates Filtering Characteristics Unaffected By Bulk Waves)

(b)

Second-Stage Filtering Characteristics
(Broken Line Indicates Filtering Characteristics Unaffected By Bulk Waves)

(c)

Two-Stage Cascade-Connected Filtering Characteristics

FIG. 6

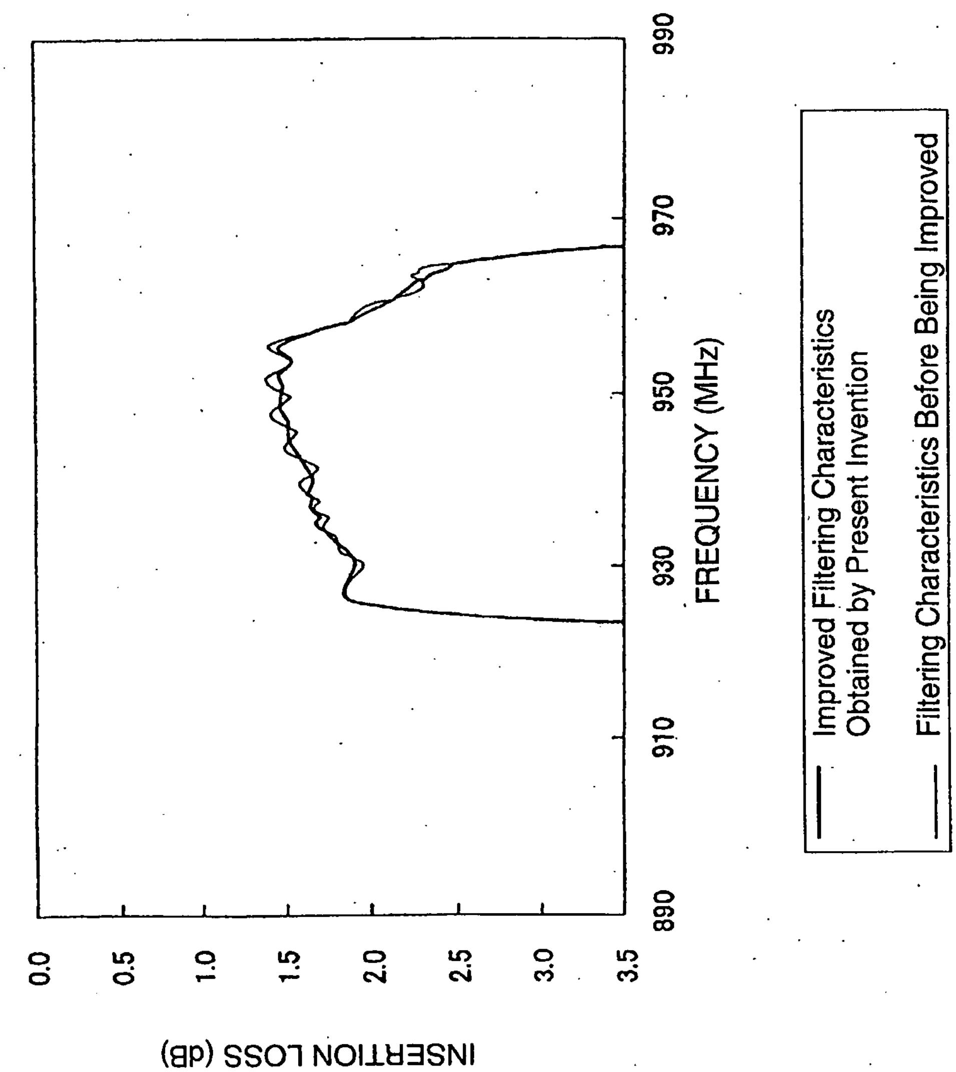

INSERTION LOSS (dB)
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
890
910
930
950
970
990
FREQUENCY (MHz)
Improved Filtering Characteristics Obtained by Present Invention
Filtering Characteristics Before Being Improved

FIG. 7

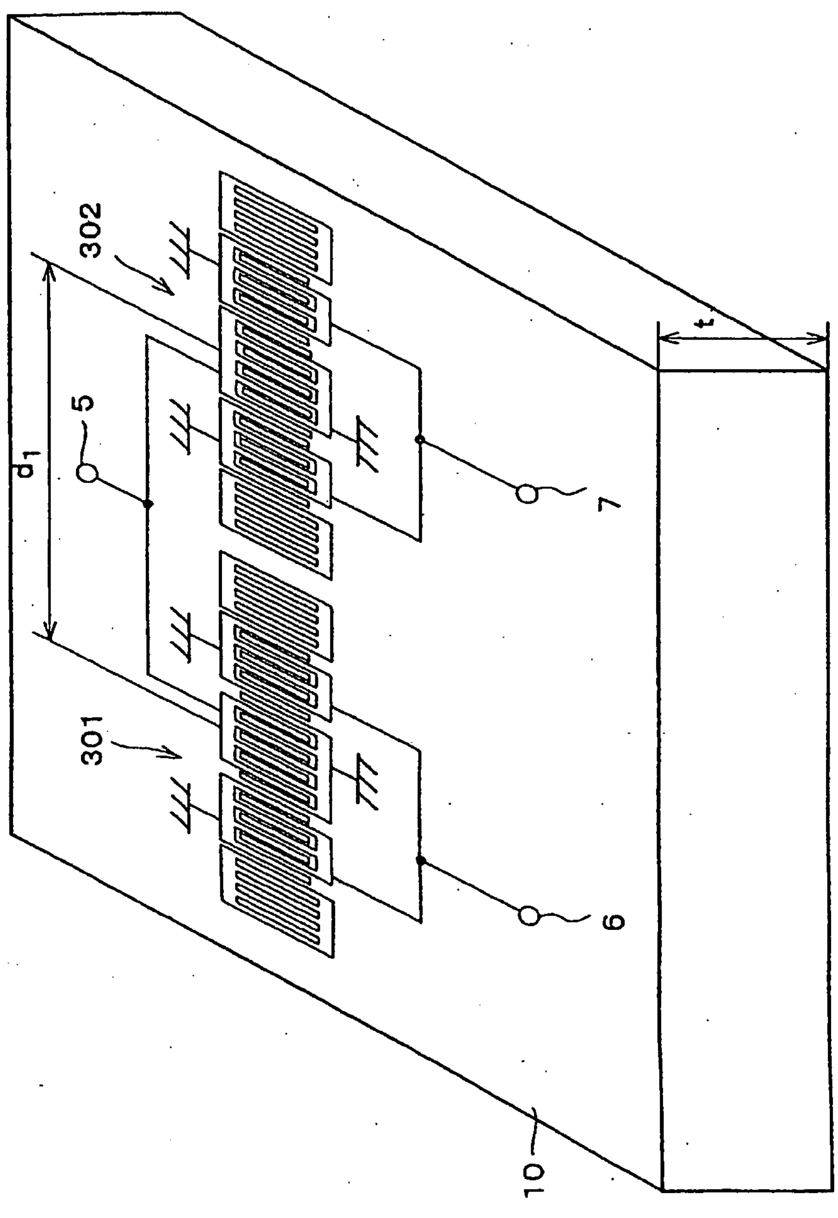


FIG. 8

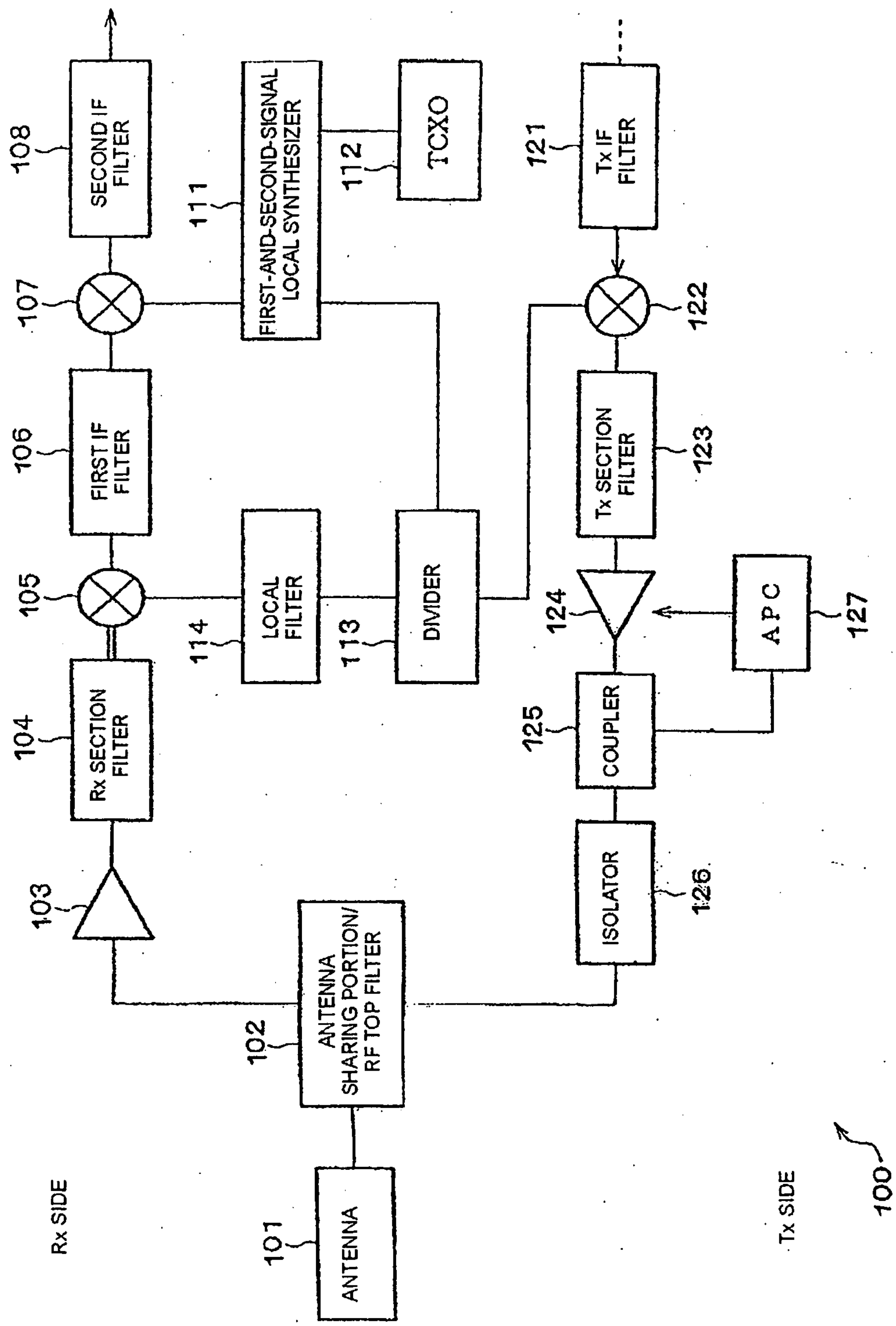
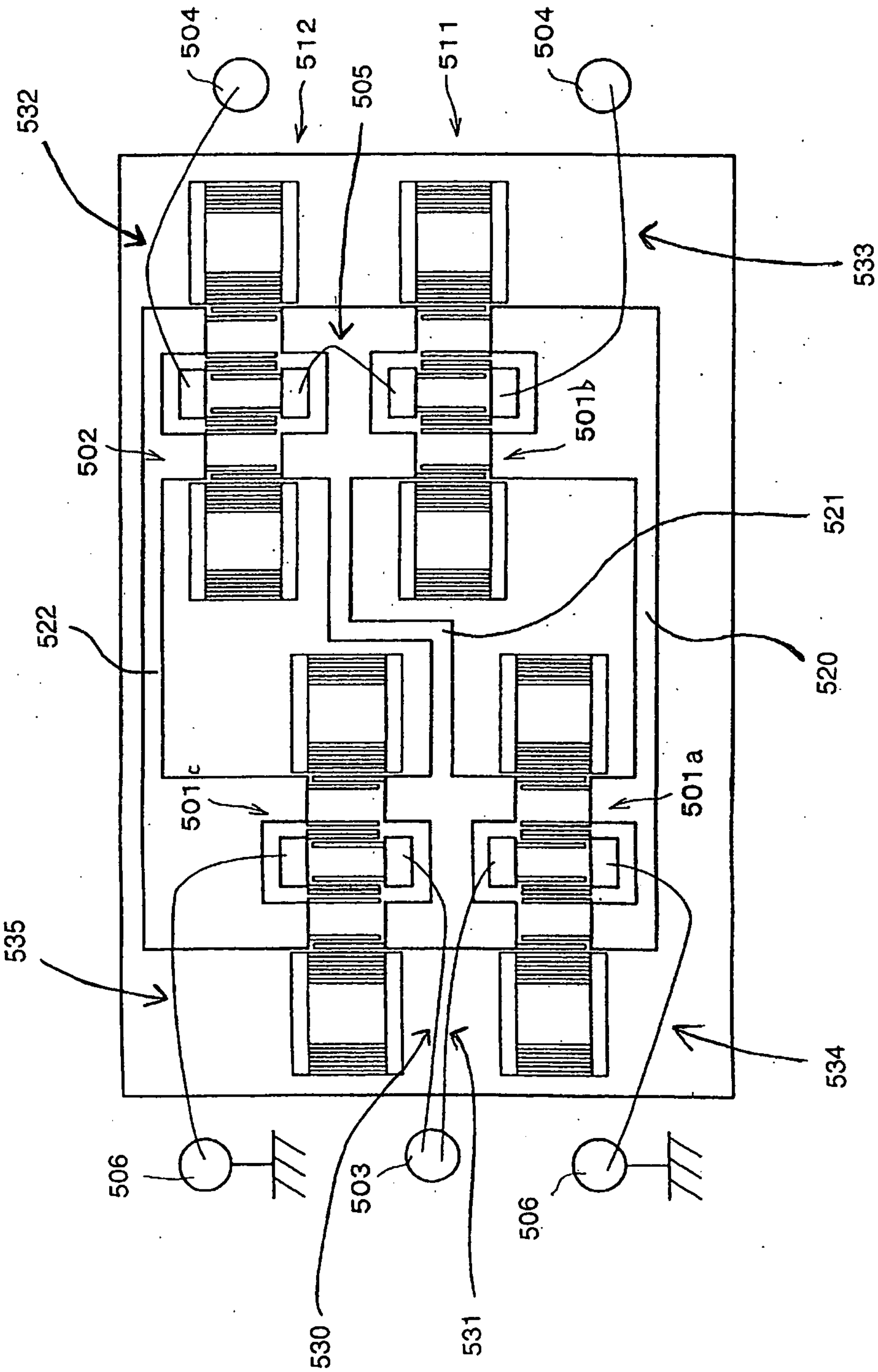

Rx SIDE
Tx SIDE
ANTENNA
101
ANTENNA SHARING PORTION/ RF TOP FILTER
102
103
Rx SECTION FILTER
104
105
FIRST IF FILTER
106
107
SECOND IF FILTER
108
FIRST-AND-SECOND-SIGNAL LOCAL SYNTHESIZER
111
TCXO
112
DIVIDER
113
LOCAL FILTER
114
Tx IF FILTER
121
122
Tx SECTION FILTER
123
124
COUPLER
125
ISOLATOR
126
A P C
127
100

FIG. 9


504
512
505
511
504
532
533
502
501b
521
522
520
501c
501a
535
534
506
503
506
530
531